Canvas Matches in Vermeer: A Case Study in the Computer Analysis of Fabric Supports

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Old master paintings were executed on various types of support, most commonly on wood panel or canvas, but also on copper and other metal sheets, and much more rarely on slabs of stone, such as slate, alabaster, or marble. The type of wood (usually oak in northern Europe and poplar in Italy) and, when possible, dendrochronology can help determine the approximate period of a painting's execution, country of origin, and, in some cases, authorship. The weave of a canvas (its pattern or fineness) may bear on the same questions or be otherwise revealing, for instance, by suggesting that two paintings were intended as a pair.[1]

For the past several years two of the present study's authors, C. Richard Johnson Jr. and Don H. Johnson, have developed computer algorithms that allow an analysis of canvas weaves that is more precise than traditional methods.[2] They have digitally mapped canvases used by European artists ranging in date from the 1450s (Dieric Bouts's *tüchlein* paintings, in London, Los Angeles, and Pasadena) to Vincent van Gogh's pictures of 1888–90 (187 canvases from that period alone).[3] The results so far have been variously revealing for those artists and for Velázquez, Vermeer, Monet, Renoir, Gauguin, and Matisse.[4]

In the case of Johannes Vermeer (1632–1675), twenty-nine of his canvases have been digitally mapped to date, out of the thirty-six paintings by him (two of which are on wood) that are generally accepted by scholars.[5] As discussed below, three canvas weave matches were found, with three different implications: a question of authenticity; another concerning chronology; and the hypothesis that two pictures were intended by the artist as a pair.

Most Dutch painters, including Vermeer, used linen canvases of a "plain" or "tabby" weave: the threads go under and over each other one at a time, forming the simplest crisscross pattern. Until very recently, distinguishing one canvas from another was largely limited to making thread counts. The standard method of thread counting uses a radiograph (X-ray image) of a particular canvas support, the lead-bearing priming of which makes the individual threads visible.[6] Threads per centimeter in both directions are counted with a pointer under magnification, with fractions estimated by eye. Several samples are taken on each canvas, perhaps four or as many as fifteen (their locations are virtually impossible to specify using this manual method). The samples on one canvas are then averaged, and the support may be said to consist of an average of about 12.5 x 17.2 threads per centimeter or a similar (by digital standards) approximation.

In our survey of twenty-nine canvases used by Vermeer, four of them present a very close correlation of thread counts in both the warp and the weft direction. Here are the average thread counts per centimeter (with height before width), as calculated automatically by computer:

1. *The Milkmaid* (Rijksmuseum, Amsterdam): 14.4 x 14.7
2. *Woman in Blue Reading a Letter* (Rijksmuseum, Amsterdam): 14.6 x 14.7
3. *Girl with a Pearl Earring* (Mauritshuis, The Hague): 14.2 x 14.1
4. *Study of a Young Woman* (The Metropolitan Museum of Art, New York): 14.3 x 14.8

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1. Johannes Vermeer (Dutch, 1632–1675). *Young Woman Seated at a Virginal*, ca. 1670–72. Oil on canvas, 9¾ x 7⅝ in. (24.7 x 19.3 cm). Private collection, New York (L29)

2. Johannes Vermeer. *The Lacemaker*, ca. 1669–70. Oil on canvas, 9⅜ x 8⅛ in. (23.9 x 20.5 cm). Musée du Louvre, Paris. Photograph: Erich Lessing/Art Resource, NY; Louvre, Paris, France (L36)

The first, second, and fourth canvases reveal thread counts so consistent with each other as to encourage conjectures about the pictures' dates or Vermeer's working methods, while the third and fourth paintings (the two *tronies*, or "head studies," in The Hague and New York) are on canvases similar enough in weave and in their present sizes (44.5 x 39 cm and 44.5 x 40 cm, respectively) to support an argument that they were painted at the same time or even intended as a pair. Computer analysis, however, proves that these four canvases come from four different bolts of cloth: in other words, there is *no* match among them, or between any one of them and the other twenty-five canvases scanned so far. To paraphrase George Orwell, two weaves may be "identical," but some are more identical than others.

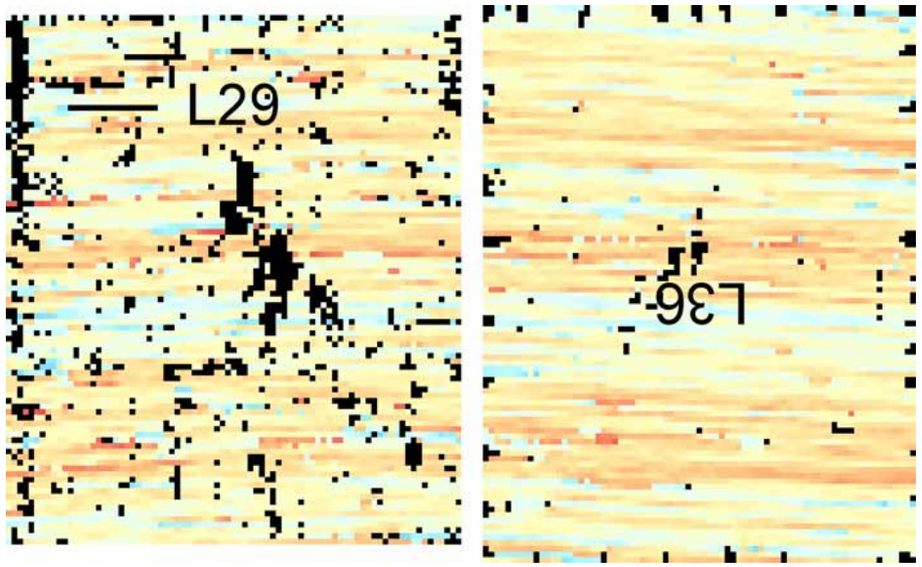
In an article of 2006 on Vermeer's *Young Woman Seated at a Virginal* (Figure 1), the conservators Libby Sheldon and Nicola Costaras published radiographs of that picture and of *The Lacemaker* (Figure 2).[7] They reported that the latter was painted, like the former, "on a canvas made of precisely the same type of rather coarse fibre . . . [with] exactly the same thread count," namely 12 x 12 threads per centimeter.[8] This turns out to be accurate for *Young Woman Seated*,[9] whereas *The Lacemaker* actually has an average of 11.9 threads per centimeter vertically and 12.4 horizontally. Thus, the match is less close than in the case of *The Milkmaid* and *Woman in Blue* (nos. 1 and 2 above). In this case, however, computer analysis confirms the suggestion by Sheldon and Costaras that *Young Woman Seated* and *The Lacemaker* "could well be from the same bolt of cloth."[10]

Fabrics differ in several qualities other than thread count, as could have been explained by the sitters in Rembrandt's *Syndics of the Clothmakers' Guild (De Staalmeesters)* of 1662 (Rijksmuseum, Amsterdam), who were responsible for monitoring the quality of the dyed woolen cloth produced by Amsterdam guild members (*staalmeester* means "sample master"). Conservators and art historians have occasionally noted canvas characteristics other than thread count. For instance, Ernst van de Wetering, writing on "the canvas support" in Rembrandt paintings, points out "characteristic differences in nature between the warp and weft threads." In a survey of radiographs, he mentions "the impression of 'fluffiness' or 'smoothness' one gets from the threads . . . A feeling develops for the 'style' of spinning or weaving, irrespective of whether these styles were dictated by material or technical circumstances or, indeed, by the individual spinners' and weavers' working habits."[11] Nonetheless, one

must accept that "the pattern in linen weave [unlike twill] is simple and invariable. The only way of comparing canvases with a linen weave is to measure the number of threads/cm in the warp and weft (a 'threadcount') and, so far as the radiograph allows, to compare the peculiarities of the yarn used."[12] Computer analysis now allows a much more detailed accounting of each linen canvas's characteristics.

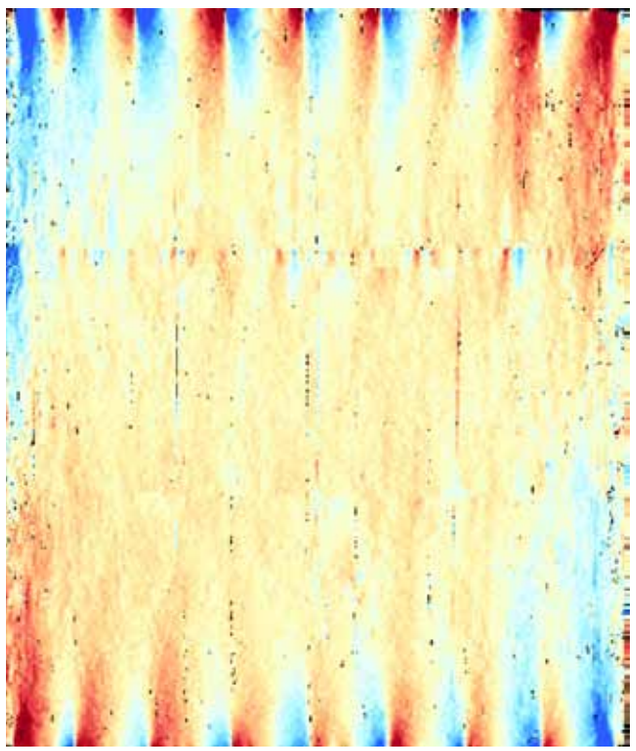
Linen threads are spun from the fibers of the flax plant, a commodity from which the Utrecht painter Joachim Wtewael (1566–1638) and his son Peter (1596–1660) "made a fine fortune," according to Joachim von Sandrart, in 1626.[13] The quality of cleaned flax fibers and standards of spinning (a cottage industry in the Netherlands) determined the consistency, fineness, and strength of linen thread. Warp threads (the vertical threads) on a loom were stretched tight and thus had to be of higher quality than weft threads. The latter (also known as "woof" or "filling yarn") are woven horizontally over and under the warp threads, with a wooden shuttle leading the weft thread (which, unless it breaks, is one continuous thread). At the end of each transverse pass the weft thread is tugged to an appropriate tautness (another variable) and then turned back to weave in the other direction. Each round-trip of the weft thread is called a "pick"; the loops to either side form a finished edge or "selvage." After each pick a comblike "reed" is used to "batten" (press down) the weft thread. If the weft thread is pulled too tautly after a horizontal pass, the battening will produce a wavy, rather than a nearly straight, line or (our own term) a "weft snake." This occurs only in weft threads woven on hand looms (or, less noticeably, when a machine loom stops). About forty percent of the Vermeer canvases surveyed so far reveals weft snakes. Each session on a loom—that is, the continuous use of the same warp and weft threads—produces a "bolt" of cloth. A "roll" is simply a length of linen cut off the bolt.

For readers of art historical literature, none of these terms will be as alarming as "algorithm," to say nothing of "spectral-maximum-based automated thread counting."[14] The formulation of particular algorithms allows supercomputers (or laptops working for a very long time) to generate automated thread counts and "weave maps" of specific kinds. "Weave density maps" (such as those in Figure 3) show variations in thread density over the entire canvas (if all of it appears in the scanned radiograph).[15] The orange-red bands in the weave map indicate a denser packing of threads than the average thread count for the canvas as a whole, and the blue stripes show a looser weave (such as when weft threads were less tightly battened down). The black squares represent areas where the radiograph was not sufficiently clear for the algorithm to produce reliable thread counts. Obviously, these "maps" are graphs, not images; gradual changes in threads per centimeter would be almost impossible to see in a radiograph of actual size. In "weave angle maps" (Figure 4), deviations from rectilinear axes are graphed, which are especially revealing of primary and secondary cusping at the edges of a canvas, but also of "weft snakes."[16]



3. Weave density maps of the canvases reproduced in Figures 1 and 2

All this data is easily stored and searchable. A computer can match thread counts between or among canvases as well as determine weaving anomalies, just as a word-processing program can quickly tell a writer how often the



4. Weave (weft-thread) angle map of Johannes Vermeer's *The Art of Painting*, ca. 1666–68. Oil on canvas, 47¼ x 39⅜ in. (120 x 100 cm). Kunsthistorisches Museum, Vienna (L26). This graph of the weft threads (running horizontally, in this case) records cusping at the top and bottom of the canvas and a horizontal weft snake about one-third from the top.

5. Johannes Vermeer. *Young Woman Standing at a Virginal*, ca. 1670–72. Oil on canvas, 20⅜ x 17¾ in. (51.8 x 45.2 cm). The National Gallery, London. Photograph: © National Gallery, London/Art Resource, NY; National Gallery, London, Great Britain (L33)

6. Johannes Vermeer. *Young Woman Seated at a Virginal*, ca. 1670–72. Oil on canvas, 20¼ x 18 in. (51.5 x 45.6 cm). Photograph: © National Gallery, London/Art Resource, NY; National Gallery, London, Great Britain (L34)

same term has been used on a single page. As larger samples are taken—say, of dozens of canvases used by Delft artists active about 1650–75—external evidence (such as paintings that are dated) might be brought to bear upon the oeuvre of Vermeer or, indeed, of another artist. The first Delft painting in the Metropolitan Museum, other than its five Vermeers, to be radiographed for the purpose of canvas weave analysis was Hendrick van Vliet's *Interior of the Oude Kerk, Delft* of 1660. While it did not provide a match with any canvas by Vermeer,[17] it is historically plausible, for example, that three works by another Delft painter, dating from the late 1650s, could be shown to have been painted on canvases coming from the same bolt as the canvas used by Vermeer for a painting such as *A View of Delft* (Mauritshuis, The Hague), which is usually dated to about 1661–63. Would we then date the famous cityscape earlier, or would there be some other explanation? For instance, might Vermeer have held a large roll of canvas in reserve, or even have bought a spare piece from the other artist? Questions like these may become easier to answer as additional computer analysis is carried out and the results are combined with other types of historical and technical evidence.

Returning to Vermeer's *Young Woman Seated at a Virginal* and *The Lacemaker* (Figures 1, 2), we find that the two canvases reveal a matching pattern of weft thread densities when one of the canvases is turned upside down (Figure 3). Such a match might also occur between a canvas with weft threads running horizontally, as here, and another canvas with weft threads running vertically (as would often be the case in a large canvas of broad format).[18] (Canvases might also match front to back, if the artist purchased pieces of an unprimed bolt of canvas and then painted different sides.)

Serious study of *Young Woman Seated at a Virginal*, a painting that was nearly inaccessible for decades, effectively began in the present century and advanced considerably with the 2006 article by Sheldon and Costaras.[19] Therefore, the main significance of the weave match seen in Figure 3 is that it confirms one of the technical arguments that have been advanced in favor of an attribution to Vermeer.[20] This match also raises the question of whether *The Lacemaker*, which is usually dated about 1669–70, should be dated somewhat later. *Young Woman Seated*, like the two pictures in the National Gallery, London (Figures 5, 6), and *The Guitar Player* (The Iveagh Bequest, Kenwood House, London), is dated about 1670–72 by Liedtke,[21] whose conjectural chronology of Vermeer's late works does not differ much from that of most other scholars. However, the dates proposed by scholars are not far apart,

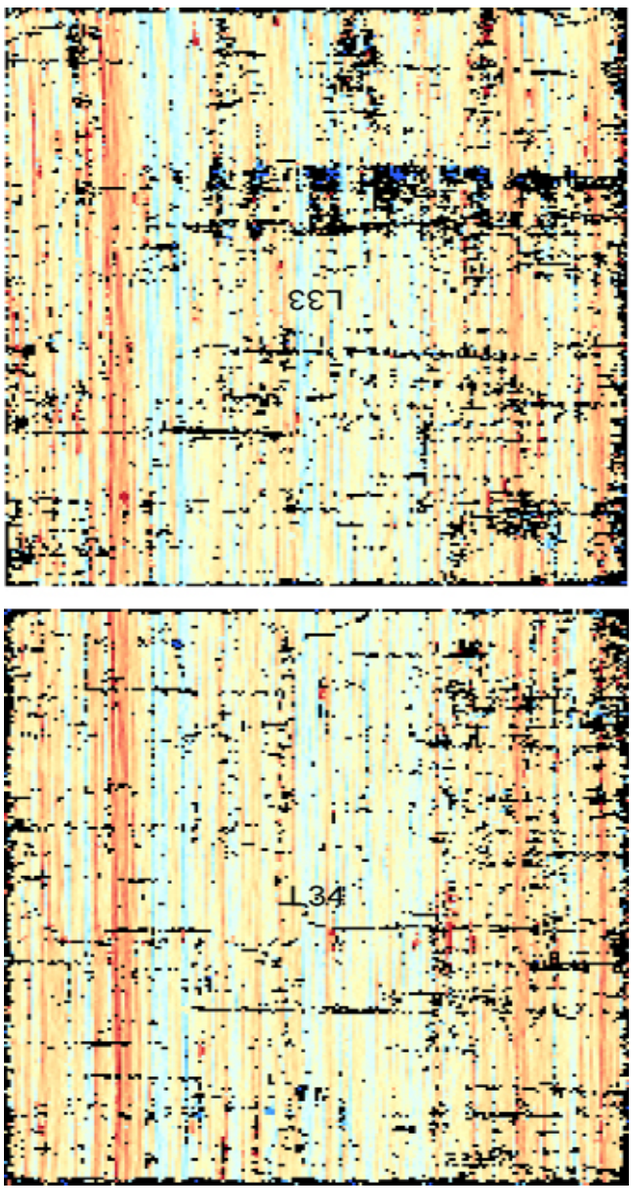
and the dating of late Vermeers is mostly guesswork, based on stylistic nuances and assumptions about the artist's life (for example, that the economic depression of 1672–75 would have discouraged him from painting at all).

A more concrete reason for leaving the chronology alone, at least in this case, is that the inventory of the house Vermeer shared with his wife and mother-in-law, dated February 29, 1676 (about two and a half months after his death), lists in the artist's studio, together with other supplies, two easels, three palettes, six panels, and "ten painter's canvases" (*10 schilderdoucken*).[22] There can be little doubt that this entry refers to ten unused, stretched, and probably primed canvases. The notary describes at greater length things he could not simply name (thus, Vermeer's maulstick is "a cane with an ivory knob on it"), and the ten canvases are listed right after the "six panels," a term that would not likely be employed by a notary for finished paintings on wood. Presumably the canvases were of different sizes and formats, offering the artist or a client choices when the next picture was begun. Nonetheless, the implications for a painter who produced, on average, no more than three finished paintings a year are clear enough: some canvas supports remained in the studio for years, and so dating by "weave match" must be supported by other evidence.

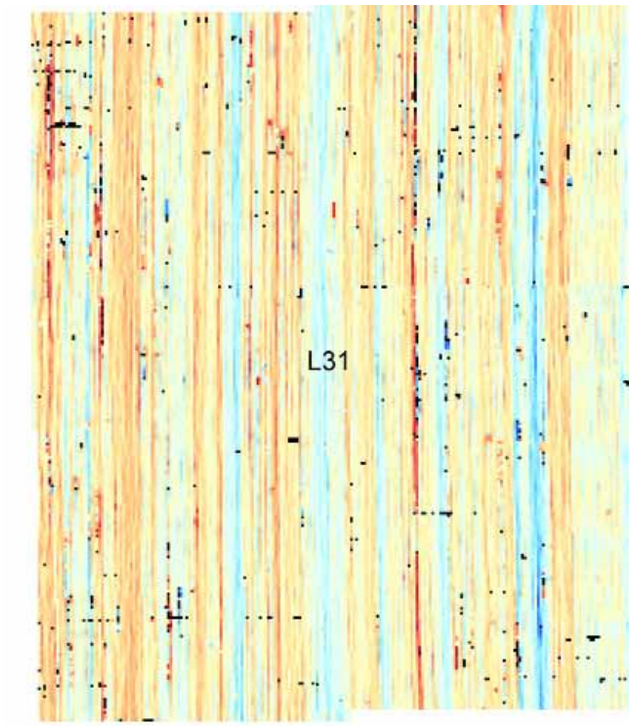
Another weave match found in Vermeer's oeuvre is between two genre paintings of identical size, *Young Woman Standing at a Virginal* (Figure 5) and *Young Woman Seated at a Virginal* (Figure 6), both in the National Gallery, London. Several scholars have doubted that the pictures were conceived as a pair and have dated the works a few years apart, invariably with *Young Woman Standing* placed earlier. Christopher Brown dated both paintings to about 1670, but doubted that they were companion pieces; Arthur Wheelock amplified this argument and dated the pictures to about 1672–73 and about 1675, respectively.[23] Liedtke, by contrast, maintains that the works are complementary in subject matter (the seated woman seems conspicuously more available than her upright counterpart) and that Vermeer used the perceived stylistic differences to express different characters and moods.[24] Moreover, the same variations in the density of warp (not weft) threads is found when the canvases are aligned top to top (Figure 7). The weave match, as shown by computer analysis, strongly supports the conclusion that the paintings were planned as pendants from the moment their canvas supports were chosen.[25]

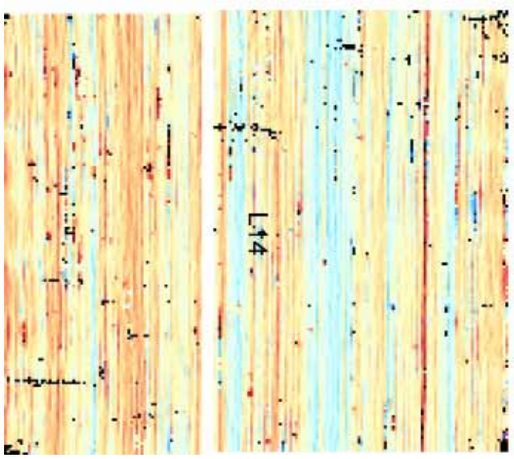
The third weave match in Vermeer's oeuvre—between *A Lady Writing a Letter with Her Maid*, in the National Gallery of Ireland, Dublin (Figure 8) and *Woman with a Lute* in the Metropolitan Museum (Figure 10)—is much less expected. The former, usually dated between 1662 and 1664, was painted on a canvas stretched with the warp threads aligned horizontally. When the picture is set on its right side (as in Figure 9), the changing density of warp threads matches the great majority of the vertically aligned warp threads in the much larger (183%) Dublin canvas. The latter is usually dated about 1670 because of the degree of abstraction that has been discerned in the modeling of the figures and the fabrics, and in what Lawrence Gowing called the "unarguable, unfeeling fall of light."[26] Stylistic arguments could be marshaled to date *Woman with a Lute* as late as 1665 and to place *A Lady Writing* in the late 1660s, but it is also possible that the smaller canvas (and perhaps another, still to be identified in our survey of Vermeer?) was cut from a roll that the artist held in reserve for some years.

It must be emphasized that this new means of investigation is still in its early stages and is subject to further refinement, both in terms of computer analysis and in the



7. Weave density maps of the canvases reproduced in Figures 5 and 6 (aligned top to top)





9. Weave density maps of the canvases reproduced in Figures 8 and 10. The painting in Figure 10 is turned on its right side for this map.

8. Johannes Vermeer. *A Lady Writing a Letter with Her Maid*, ca. 1670–71 (?). Oil on canvas, 28⅜ x 23½ in. (72.2 x 59.7 cm). The National Gallery of Ireland, Dublin. Photograph: Bridgeman-Giraudon/Art Resource, NY; National Gallery of Ireland, Dublin, Ireland (L31)

10. Johannes Vermeer. *Woman with a Lute*, ca. 1663. Oil on canvas, 20¼ x 18 in. (51.4 x 45.7 cm). The Metropolitan Museum of Art, New York, Bequest of Collis P. Huntington, 1900 (25.110.24) (L14)

application of the methodology to paintings.[27] And, of course, weave matches in canvases used by Vermeer or by another artist or by several painters at a particular time and place (for example, Rembrandt's workshop in Amsterdam) must be considered along with many other technical and historical factors. Vermeer's oeuvre, however, is something of an ideal test case because of its small size and the strong evidence that the artist worked in comparative isolation, with no known pupils or assistants. For the artist known in the nineteenth century as "the Sphinx of Delft," any new evidence must be woven into a fabric of fresh questions: for that kind of material there is no match.

NOTES

1. For instance, Charlotte Hale dated the Metropolitan Museum's *The Supper at Emmaus* by Velázquez to his formative period in Seville (1618–23) partly on the basis of the patterned weave of its canvas, called *mantelillo* or *mantel*, a type used by painters working in Naples, Toledo, and Seville, but not in Madrid, where the artist moved in 1623. Hale 2005.
2. The Cornell University website of C. Richard Johnson Jr. describes Professor Johnson's computer-assisted analysis of canvas features and includes a bibliography (with links) of articles on this subject; see http://people.ece.cornell.edu/johnson/.
3. The evidence for Bouts will be incorporated in Wolfthal and Metzger n.d. (forthcoming). On Van Gogh, see Van Tilborgh et al.

2012. A case of particular interest is Van Gogh's *Garden of the Asylum* of 1889 (Van Gogh Museum, Amsterdam), which has been rejected as authentic (as recently as 1999) by some writers and defended by others. The previous thinking is summed up by Hendriks and Van Tilborgh 2001. The work was executed on a canvas cut from the same bolt of cloth as were canvases employed for unquestionable works by the artist. See D. Johnson, C. R. Johnson, and Hendriks 2013 (forthcoming).

4. The canvas on which Velázquez, in 1644, painted the "Fraga Philip" (*King Philip IV of Spain*, The Frick Collection, New York)—so-called because it was carried out on short notice in Fraga, Aragon, near the rebellious province of Catalonia—comes from the same bolt as the undated *Sebastián de Morra* (Museo del Prado, Madrid), which has been described as "the most forceful of all the dwarf portraits" because of its similarly direct presentation and bravura handling. See Brown 1986, p. 174. On the conservation of the "Fraga Philip" by Michael Gallagher, Sherman Fairchild Conservator in Charge, Paintings Conservation, MMA, see Pérez d'Ors and Gallagher 2010; on the *Sebastián de Morra*, see Pérez d'Ors, C. R. Johnson, and D. Johnson 2012 (forthcoming).
5. For a complete catalogue, see Liedtke 2008.
6. See Van de Wetering 1986 (reprinted, with some revisions, in Van de Wetering 1997, pp. 91–130).
7. Sheldon and Costaras 2006. In the present article, the "L" numbers in the captions and graphs refer to the catalogue of Vermeer paintings published in Liedtke 2008.
8. Sheldon and Costaras 2006, p. 92. The complete phrase ("exactly the same thread count for an area of 12 by 12 cm") is misleading. What was meant is that the canvas as a whole has an average of twelve threads per centimeter in both directions.
9. The automated thread count showed an average of 12 x 12 threads per centimeter for the entire canvas of *Young Woman Seated at a Virginal*. C. Richard Johnson Jr. then measured thread counts by hand in about sixty locations (thirty in each direction); they were found to average 12.1 threads per centimeter vertically and 12.4 horizontally.
10. Sheldon and Costaras 2006, p. 92.
11. Van de Wetering 1986, p. 23.
12. Ibid., p. 19. See also Sheldon and Costaras 2006, p. 92, on irregularities seen in raking light.
13. As quoted in Lowenthal 1986, p. 30. Paintings by both Wtewaels are in the Museum's collection: see Liedtke 2007, pp. 975–91.
14. See note 2 above for links to the articles "Advances in Computer-Assisted Canvas Examination: Thread Counting Algorithms" and "On the Utility of Spectral-Maximum-Based Automated Thread Counting from X-Radiographs of Paintings on Canvas."
15. The X-ray must be scanned at a suitable resolution (typically 600 dpi where i = one inch on the painting's surface) for reliable digital image processing.
16. On primary and secondary cusping, see Van de Wetering 1986, pp. 31–33. The authors are grateful to conservator Elke Oberthaler for providing radiographs of Vermeer's *The Art of Painting* (Kunsthistorisches Museum, Vienna).
17. The painting did reveal a quite unexpected formal portrait of a man, almost surely by Van Vliet himself, under the architectural view. See Liedtke 2007, pp. 922–24.
18. See Van de Wetering 1986, pp. 37–42, on "strip-widths and painting formats." A roll of canvas one *ell* wide (about 72 cm) would, for example, normally be used horizontally (with warp threads running from side to side, not top to bottom) for a painting that was about 68 cm high and 100 cm wide. Thus, a seam in the canvas support (or the purchase of a bolt of canvas of custom-made width) is avoided.
19. Because (ex-catalogue) the painting was so little known in the original, it was included without attribution in the Museum's 2001 exhibition "Vermeer and the Delft School."
20. The technical evidence is summarized, and stylistic analysis added, in Liedtke 2008, no. 36. See also Sheldon 2007, pp. 99–101.
21. Liedtke 2008, nos. 29, 33–36.
22. Montias 1989, p. 341, under doc. no. 364.
23. Brown in MacLaren and Brown 1991, pp. 466–68; Wheelock 1995, nos. 21, 22.
24. Liedtke 2008, nos. 33, 34.
25. With regard to Rembrandt portraits, Van de Wetering 1986, p. 23, observes: "In most cases where two canvases have been identified as coming from the same bolt, the paintings concerned are companion-pieces."
26. Gowing 1970, p. 153. On the dating of the Dublin canvas, see Liedtke 2008, no. 31.
27. In a future study C. Richard Johnson Jr. will attempt to replicate canvas-stretching techniques used during different periods and to judge the consequences for weave maps.

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